Hurricane Ike along the upper Texas coast: An introduction

By

Nicholas C. Kraus, Ph.D., and Lihwa Lin, Ph.D.

U.S. Army Engineer Research and Development Center,
Coastal and Hydraulics Laboratory, 3909 Halls Ferry Rd., Vicksburg, MS 39180
Nicholas.C.Kraus@usace.army.mil

ABSTRACT

This paper serves as an introduction for a group of papers documenting the severe coastal damage caused by Hurricane Ike that struck the Texas coast and southwest Louisiana coast in mid-September 2008. Background is first given to orient readers to the coastal area. The unusually long storm surge accompanying the hurricane is examined and its consequences for evacuation and property damage noted. Selected observations of damage to structures on west Galveston Island are then presented.

ADDITIONAL KEYWORDS: Beach, erosion, hazard, Galveston, seawall, storm surge.

Manuscript submitted 3 February 2009, revised and accepted 24 March 2009.

On Saturday, 13 September 2008, Hurricane Ike made an early-morning landfall near Galveston, TX, killing scores of people in Texas and other U.S. states (as well as in Haiti and Cuba). The hurricane caused billions of dollars of damage to property, reduced the tax bases of several counties and cities, blocked federal navigation channels of national interest, and ultimately led to the loss of thousands of jobs. The U.S. Federal Emergency Management Agency (FEMA) reported that about 1.9 million people evacuated prior to Hurricane Ike (http://www.fema.gov/news/newsrelease.fema?id=47108), a success story.

Hurricane Ike was a devastating storm, but local, state, and federal government institutions were well prepared. To document experiences and lessons learned from Hurricane Ike, the *Shore & Beach* editorial board approved development of a group of papers on the subject. Contributions were invited, and the submissions were reviewed and coordinated for content. The papers had to be written within three months to meet a tight schedule for publication before the 2009 hurricane season. The assembled papers reflect freshness and depth of personal experience from the storm and its aftermath, and it is anticipated that these contributions will benefit coastal residents, decision makers, and engineers and scientists around the world who must deal with coastal hazards. An orientation map of the Texas coast is presented in Figure 1, and Figure 2 shows the upper Texas coast, defined for this paper as running from the Sabine Pass to the city of Freeport. Anderson (2007) describes the geologic history of the upper Texas coast and its vulnerability to hurricanes. Southwest Louisiana to the north and South Padre Island on the southern end of Texas are also covered in the group of papers, demonstrating the great length of coast (approximately 400 miles or 650 km) attacked by Hurricane Ike. Locations of many towns, and coastal inlets, and the tide gauges discussed in this and related Hurricane Ike papers of this *Shore & Beach* issue on Hurricane Ike are marked in these two figures.

2008 HURRICANE SEASON FOR TEXAS

The 2008 Atlantic hurricane season was a difficult one for residents and businesses, as well as for all levels of government with responsibility along the Texas coast and the Gulf of Mexico. Since the record-setting damage of Hurricane Katrina in 2005, residents and decision makers have been challenged to avoid hurricane-warning fatigue. The eye of Hurricane Ike made landfall at Galveston at 2:10 am local time (Central Daylight time) on Saturday, 13 September 2008, with 110-mph (177-km/hr) wind, according to the Lake Charles Office, Louisiana, of the National Weather Service (http://www.srh.noaa.gov/lch/ike/ikemain.php). Ike was a major coastal disaster for the upper Texas coast (Ewing *et al.* 2009; McLellan and Lee 2009; Tirpak 2009; Watson 2009; Williams *et al.* 2009), with influence extending from southwest Louisiana (Byrnes and McBride 2009) to South Padre Island, Texas (Heise *et al.* 2009). Hurricane Ike had unusually long surge duration, discussed below, with destruction and casualties belying its Category 2 classification by wind speed. A surge is a relatively slow rise in water level typically occurring over several hours for hurricanes, but which can persist for days for unusual storms, as is shown for Ike.

In 2008, Ike was preceded by three other hurricanes on the Texas coast. Hurricane Dolly struck the lower Texas coast (Brownsville and the Rio Grande Valley) on 23 July. Dolly caused wind damage and flooding by precipitation and surge in the bay (Laguna Madre), but not significant erosion on the Gulf of Mexico shore on Padre Island as compared to that produced during the long duration of elevated water level of Ike. Tropical Storm Edouard made landfall northeast of Galveston at the McFaddin National Wildlife Refuge on 2 August. Hurricane Gustav hit Cocodrie, on the southwest coast of Louisiana on 1 September, with great damage by wind and precipitation in the state capitol, Baton Rouge, and vicinity. Many businesses and residents in New Orleans who had relocated to Baton Rouge during the three years after Hurricane Katrina again experienced extensive damage and misery by Hurricane Gustav, including a long power outage.

Damage by Hurricane Ike and the well-managed pre- and post-storm responses hold valuable lessons for coastal cities and society. *Shore & Beach* has a

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **Hurricane Ike along the upper Texas coast: An introduction**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Engineer Research and Development Center,Coastal and Hydraulics Laboratory,3909 Halls Ferry Rd,Vicksburg,MS,39180**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

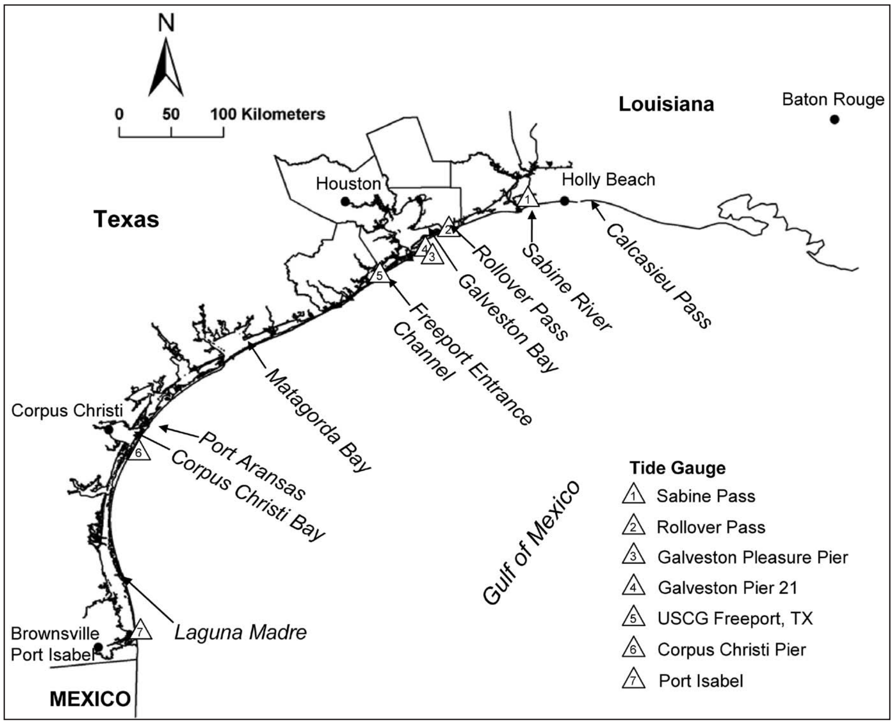


Figure 1. Map of the Texas coast with tide gauges discussed in this issue.

long tradition of storm reports, which began in it inaugural issue of April 1933. *Shore & Beach* Volume 76, No. 4, 2008, is devoted to coastal cities, including an article on hazard risk and potential adaptation strategies (Ewing 2008). "The Hidden Costs of Coastal Hazards" (H. John Heinz III Center 2000) is recommended for an in-depth study of the direct and indirect costs of weather-related hazards. Hurricane Hugo that struck South Carolina in 1989 is taken as a case study in the Heinz Center book, including lessons learned from follow-up work on the recovery effort.

Galveston Island and the Galveston seawall have been featured several times in *Shore & Beach* articles, including an early description of the beach, seawall, and erosion (Washington 1938), and the design and excellent performance in protecting the city against the surge and waves of 1961 Hurricane Carla (Davis 1961). Both of these references mention the presence of high sand dunes running along the east end of Galveston Island that were removed early in city development to allow access to the beach and to serve as fill for the grade raising. Watson (2009) discusses the potential functioning of dune ridges as natural seawalls. In contrast to the protection afforded by the seawall, low and narrow barrier beaches flank the city of Galveston to the east on Bolivar Island and to the west. Therefore, responses to Hurricane Ike were vastly different for the unprotected beach on the right-front quadrant (east) of the storm's eye, the area protected by the seawall, and the unprotected beaches on the left-front quadrant (west) of the eye.

GALVESTON SEAWALL

Galveston is an active port city and a historic summer beach recreational destination. The year 2000 U.S. Census counted 57,247 residents in the city of Galveston and 250,158 residents in Galveston County. The city of Galveston is protected from storms in the Gulf of Mexico by a substantial 10-mile (16 km) long seawall built in response to great loss of life and damage from the Category 4 September 1900 hurricane. Much of the material in following paragraph was adapted from U.S. Army Corps of Engineers (USACE) (1981).

In 1901, the City Commission of Galveston and the County Commissioners Court of Galveston appointed a board of three eminent engineers to develop a means for protecting the city. This board was led by retired Brigadier General Henry Martyn Robert, a former Chief of Army Engineers, and the author of the celebrated "Robert's Rules of Order" (first published in 1876). The Robert Board submitted its report on 25 January 1902, recommending construction of a seawall and ground raising that formed the basis for the wall and land configuration as seen today. Galveston County constructed the originally specified 17,593 ft (5.36 km) length of seawall by July 1904. The U.S. Congress authorized a seawall segment, completed in October 1905, that extended 4,935 ft westward along the front of the then-Fort Crockett Military Reservation. Subsequent eastward extensions by local and federal funding were completed in 1913 and 1923-1926, and 3 miles (4.8 km) westward in 1953. The total length of the present seawall is 55,790 ft (10.04 miles, 17.00 km), Following the 1900 storm, the seawall and grade raising with associated storm drains have protected the city of Galveston from numerous hurricanes such as those in 1909, 1915, 1919, 1932, 1941, 1943, 1949, 1957, 1961 (Carla), 1983 (Alicia), 2003 (Claudette), and 2005 (Rita).

The seawall itself is protected from scour by large stones that have been placed at its base, and 15 rubble stone groins (originally built in the 1930s, and upgraded to stone in the 1960s) were constructed to hold the beach as further protection. However, the beach gradually eroded and narrowed, and the first engineered open-coast beach fill (beach nourishment) was placed there in 1995-1996 (McKenna, Brown, and Kraus 1995) by the city of Galveston with assistance from the Texas General Land Office (TGLO).

HOUSTON-GALVESTON SHIP CHANNEL

The Houston-Galveston ship channel runs about 50 miles (80 km) north from Galveston to Houston, TX, and serves the Port of Houston. This port is the sixth largest in the world, ranking first in the United Stated in foreign waterborne commerce and second in total tonnage. Three of four primary Texas port zones are located on the upper Texas coast. After Hurricane Ike, deep-draft ship channels had to be surveyed and cleared of obstructions immediately, including rehabilitation of sites serving for placement of dredged material (Tirpak 2009).

Priority ports were Sabine-Neches (Port Arthur, Beaumont, and Orange), Galveston Bay (Galveston, Texas City, and Houston), Freeport, and Aransas Pass (Corpus Christi). According to USACE records, in year 2006 these four port areas cumulatively accounted for nearly 500 million short tons (454 million metric

tons) of waterborne tonnage and handled 25% of all foreign (imports and exports) tonnage traveling on U.S. waterways. Crude petroleum tonnage was 35% of the national total. Other significant commodity totals include gasoline (19.8% of national coastwise total), distillate fuel oil (24.3% of national coastwise total), wheat (22.4% of national coastwise total), and benzene and toluene (72% of national coastwise total). Clearly, recovery of the coastal navigation channels and associated waterways such as the Gulf Intracoastal Waterway was of national urgency after Hurricane Ike (Tirpak 2009).

HURRICANE IKE SURGE

Hurricane intensity is often ranked with the Saffir-Simpson Hurricane Scale (SSHS), a rating system that defines five categories from 1 to 5 (http://www.nhc.noaa.gov/aboutsshs.shtml). The SSHS is well suited for warnings and preparations pertaining to wind damage. In this ranking system, Category 1 is the least severe with 1-minute averaged wind speed ranging from 74 mph to 95 mph (119-153 km/hr), and Category 5 is the most severe with wind speeds exceeding 155 mph (249 km/hr). Although wind can cause extensive damage to structures and poses a danger to human life through hurling of objects, wind speed offers an indirect and incomplete measure for classifying beach erosion and hurricane surge inundation and overwash. Hurricane Ike made landfall as an upper-end Category 2 hurricane with wind speeds between 96 mph and110 mph (154-177 km/hr).

A storm surge is a rise in water level above the predicted astronomical tide as associated with a tropical storm (includes hurricanes) or extratropical storm. Although a strong wind shear and low pressure (inverse barometer effect) are the common forcing mechanisms of storm surge, large storms in the Gulf of Mexico can induce basin or Gulf-wide oscillations that elevate the water level (Bumpapong, Reid, and Whitaker 1985). Such an oscillation can result in a notable forerunner wave (surge contribution) arriving to the coast before the major surge by wind and low atmospheric pressure, and the hurricane eye. Forerunner development depends on the track, size of the hurricane or storm, and the location of hurricane landfall.

Hurricane Ike occupied a substantial portion of the Gulf of Mexico, and its track

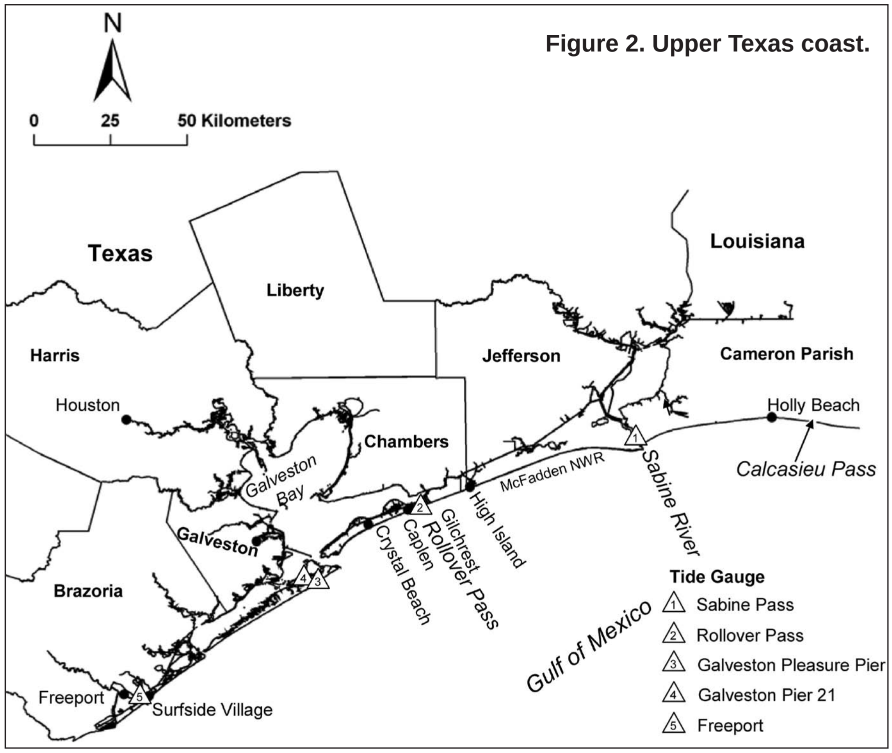


Figure 2. Upper Texas coast.

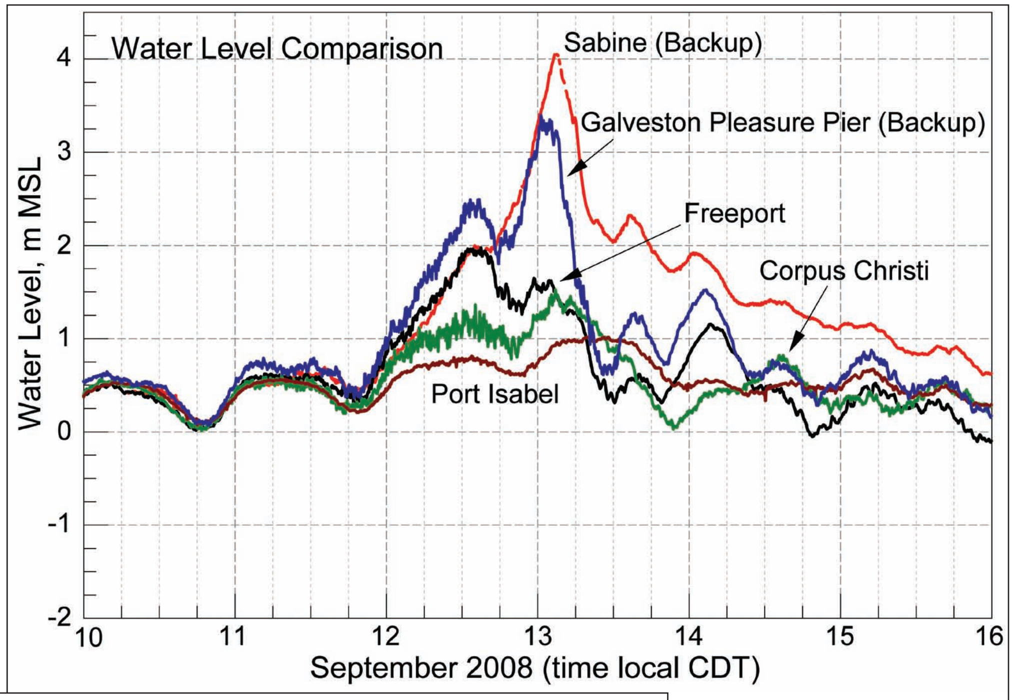
and energy induced a large forerunner, as shown in the water levels plotted in Figure 3. These water level gauges are operated by the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration and are mounted on piers extending into the nearshore of the Gulf (Galveston Pleasure Pier, Corpus Christ Pier) or just inside large coastal inlets (Sabine, Freeport, Port Isabel). The data shown were considered preliminary by NOS at the time of writing this paper and may be subject to change. In particular, the authors plotted portions of the water level from the secondary or backup gauges at the Galveston Pleasure Pier (known as Flagship Pier locally) and Galveston Pier 21, because the primary (acoustic) gauges failed or gave questionable results. Backup gauges at these sites are based on water pressure, vented to the atmosphere to eliminate barometric pressure. A likely forerunner surge arrived around 10 p.m. local time on Thursday evening, 11 September. However, there may have been an earlier forerunner that started that morning. Figure 3 indicates that the surge was greatest at Sabine, located in right-front quadrant of the wind with respect to the eye that entered Texas at Galveston. The peak surge then decreased with distance south, although the duration remained much the same. The surge duration of a typical hurricane is less than a day, but the duration of Ike was approximately 2½ days. Such surge has profound consequences for causing beach erosion, as discussed in the next section, and for promoting wave forces on structures high on the beach (Ewing *et al.* 2009).

Water level in Galveston Bay on the north side of Galveston Island measured at the Pier 21 gauge rose synchronously with that in the Gulf of Mexico (Figure 4) measured at the Pleasure Pier gauge. The Gulf or south side of Galveston Island was raised following the 1900 hurricane during construction of the seawall (Davis 1961; USACE 1981), which provided protection from surge and waves, and improved storm drainage. However, the city area of Galveston Island slopes downward toward the bay and harbor. The bay side of Galveston was flooded by the evening of Friday, 12 September, with primary water intrusion believed to be from the bay side. Anecdotally, many residents who delayed evacuation were prevented from doing so by the forerunner, likely believing that the eye of the storm and, therefore, greatest storm intensity were still offshore. For reference, the predicted tide at the Galveston Pleasure Pier is shown in Figure 4. The tide is predominantly diurnal on this coast with diurnal range of about 0.6 m (2.0 ft).

BEACH DAMAGE BY STORMS

Storms are a hazard through extreme wind, precipitation, flooding by surge

Figure 3 (right). Water level measured at several locations along the Texas coast during Hurricane Ike. The eye of the hurricane made landfall at 2 am on Saturday, 13 September, but the main surge was preceded by a large forerunner wave that arrived before midnight of Thursday, 11 September. Data plotted downloaded from http://tidesandcurrents.noaa.gov/ and includes preliminary or unverified values.



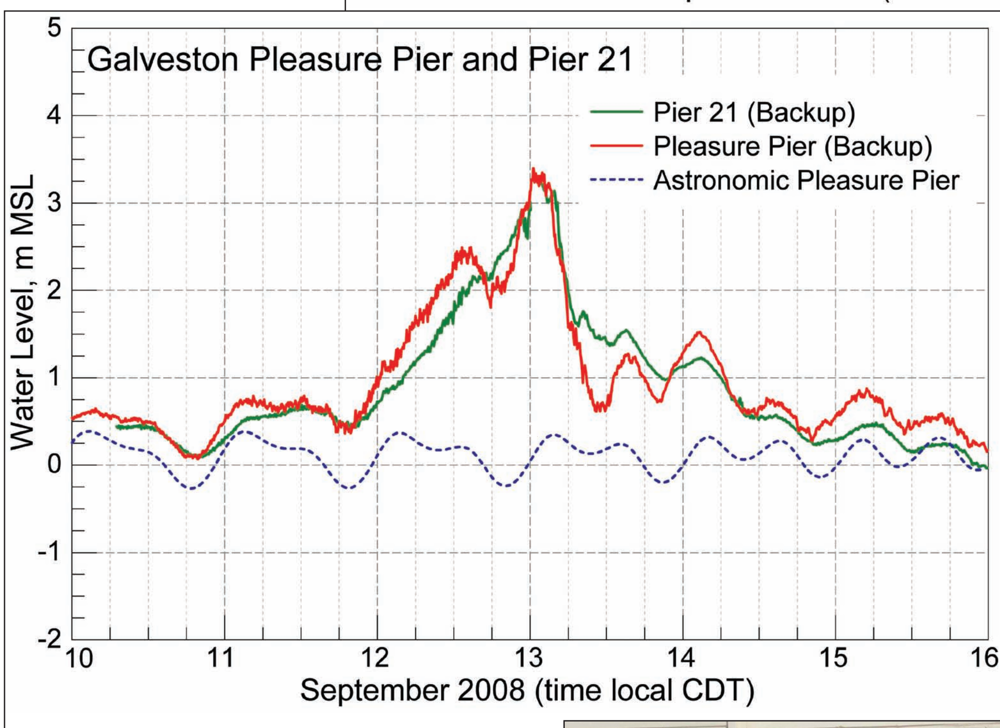


Figure 4 (left). Times series of observed water level and predicted (astronomical) tide at the Galveston Pleasure Pier (Gulf of Mexico) and Pier 21 (Galveston Bay, on other side of the barrier island from the Pleasure Pier site). The observed water level includes the surge and the tide. Data plotted downloaded from http://tidesandcurrents.noaa.gov/ and includes preliminary or unverified values.

Figure 5 (right). Undermining of concrete slabs of beach residences on west Galveston Island.

Figure 6 (above). Undermining of concrete slabs was progressively less with distance landward (to right of picture).

Figure 7 (left). Up and down movement of heavy concrete slab by the surge current and waves scraped this large piling, rounding and weakening it from its orginal square shape.

Figure 8 (below). Flood damage by surge on structure facing the Gulf of Mexico, but more than 1,500 ft (450 m) from the beach.

and runoff from land and rivers, wave forces, and erosion. Elevated water level and waves are the main contributors to erosion and damage to structures near the beach. Abnormally high water during a storm surge allows waves to penetrate inland. Dunes and beaches can be eroded either by loss of sand to the sea or by landward movement during the flood. The longer the duration of high water level, the more the barrier islands can be inundated, and beach sand either carried offshore or transported landward. Bolivar Peninsula to the north of Galveston and the beaches directly to the south had no protective dunes and thus were inundated, overwashed, and severely eroded.

On 23 October 2008, the first author inspected the beaches west of the city of Galveston. Almost all residences and buildings gulfward of the Blue Water Highway are on pilings. Blue Water Highway is a scenic coastal drive (connecting to Farm-to-Market Road 3005) that runs some 40 miles (64 km) from Seawall Boulevard in the city of Galveston to Surfside Village in Brazoria County. Structures on pilings fared well under the long duration of extreme water level, surge, and waves. However, the concrete slabs under the buildings closest to the beach were extensively undermined (Figure 5). Damage by erosion was progressively less with distance landward from the beach (Figure 6).

Buildings near the beach are inferred to have been damaged primarily by erosion induced by surge and waves, which undermined the massive concrete slabs under them. Some slabs were moved energetically by waves and the flooding current from the sea to bay, as seen in Figure 7. This photograph indicates that the slab was repeatedly moved up and down by hydrodynamic forces. Such movement stressed the pilings, tilted the structure, and caused damage that otherwise might not have occurred. Concrete slabs are constructed primarily for parking beneath the main dwelling and to serve as a foundation for large appliances and water heaters. A conclusion is that concrete slabs should not be placed under structures built on pilings that may be exposed to surge and waves. A gravel layer on top of filter cloth might be an appropriate and low-cost alternative.

Older structures not on pilings were heavily damaged by the surge. The picture in Figure 8 shows such a structure, a restaurant located on the bay (north) side of FM 3005, some 1,500 ft (450 m) from the beach. Debris was driven into the building by the surge from the Gulf of Mexico and its functionality as a restaurant was destroyed.

CONCLUSIONS

Hurricane Ike, which made landfall at Galveston on 13 September 2008, was a devastating storm for the upper Texas coast, primarily because of the long duration of its surge. The surge caused prolonged flooding of structures and allowed waves to reach far inland. Beaches and wetlands from southwest Louisiana to South Padre Island, TX, were damaged. The venerable Galveston seawall protected the city from the sustained surge and waves. A forerunner surge and its flooding arrived much before the eye of the storm, increasing damage and hindering or preventing some evacuations.

Much of downtown Galveston near the bay was flooded because of almost simultaneous rise of the bay in response to the surge in the Gulf of Mexico and the low land elevations there. The elevated area of Galveston located near the seawall incurred much less damage. Several towns adjacent to the city of Galveston that were without dune or seawall protection were destroyed or severely damaged, and short- and long-term economic loss was great. Evacuation of residents and government responses to the storm were remarkably successful in reducing the loss of human life and in restoring critical functions of local and national significance. The amounts and kinds of damage by Hurricane Ike, consideration of surge and not mainly wind speed for evacuation, as well as the performance at all levels of government make Hurricane Ike a valuable example for storm-damage consequences and preparations that must be considered by all coastal cities.

ACKNOWLEDGEMENTS

The efforts of the authors of Hurricane Ike papers in this issue of *Shore & Beach* are greatly admired and appreciated. The authors of this paper would like to thank Lee Butler, Rusty Feagin, William Grosskopf, Kim McKenna, Ned Mitchell, Julie Rosati, and Richard Watson for valuable discussions or comments. This paper is a product of the Coastal Inlets Research Program, administered by Headquarters, U.S. Army Corps of Engineers (HQ, USACE). Permission was granted by HQ, USACE, to publish this information.

REFERENCES

Anderson, J.B., 2007. *The formation and future of the upper Texas coast*, Texas A&M University Press, 163 p.

Bumpapong, M., R.O. Reid, and R.E. Whitaker 1985. "An investigation of hurricane-induced forerunner surge in the Gulf of Mexico," Tech. Report CERC-85-5, Coastal Engineering Research Center, U.S. Army Engineer Research and Development Center, Vicksburg, MS, 201 p.

Byrnes, M.R., and R.A McBride 2009. "Coastal response to Hurricane Ike: Southwest Louisiana and southeast Texas," *Shore & Beach*, 77(2).

Davis, A.B., Jr., 1961. "The Galveston sea wall," *Shore and Beach*, 29(2), 6-13.

Ewing, L., 2008. "Coastal megacities and hazards: Challenges and opportunities," *Shore & Beach*, 76(4), 36-41.

Ewing, L., and others 2009. "Field investigation of Hurricane Ike impacts to the upper Texas coast," *Shore & Beach*, 77(2).

H. John Heinz III Center for Science, Economics and the Environment 2000. *The Hidden Costs of Coastal Hazards*, Island Press, 220 p.

Heise, E.A., J.A. Benavides, M. Contreras, A. Cardenas, and J. Lemen 2009. "Hurricanes Dolly and Ike damaged the Town of South Padre Island from two different directions in 2008," *Shore & Beach*, 77(2).

McKenna, K.K., C.A. Brown, and N.C. Kraus 1995. "The first open-coast beach fill in Texas." *Proc.1995 National Conf. on Beach Preservation Technology*, FSBPA, 88-101.

McLellan, T.N., and M. Lee 2009. "Post-Hurricane Ike ground observations on Bolivar Peninsula, Texas," *Shore & Beach*, 77(2).

Tirpak, S.M., 2009. "United States Army Corps of Engineers, Galveston District experiences and response to Hurricane Ike," *Shore & Beach*, 77(2).

U.S. Army Corps of Engineers (USACE) 1981. "Galveston's bulwark against the sea; history of the Galveston seawall," U.S. Army Corps of Engineers, Galveston District, TX, 30 p.

Washington, C.C., 1938. "Galveston Island shoreline and protection of Galveston Beach," *Shore and Beach*, 6(3), 105-108.

Watson, R.L., 2009. "Evaluation of coastal response to Hurricane Ike through pre-storm and post-storm aerial photography," *Shore & Beach*, 77(2).

Williams, A.M., R.A. Feagin, W.K, Smith, and N.L. Jackson 2009. "Ecosystem impacts of Hurricane Ike on Galveston Island and Bolivar Peninsula: Perspectives of the Coastal Barrier Island Network (CBIN)," *Shore & Beach*, 77(2).